Design of a generic framework for Remote Laboratories Architecture

Synopsis

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1. Introduction

Laboratory is the place where theoretical concepts are examined, tested and new ideas evolved. In the field of science and engineering hands–on laboratory experience plays a major role allowing students to physically understand theoretical concepts and therefore promoting complete education [Feisel, L. D. et al. 2005]. A quick review can reveal that most real labs despite their set of highly sophisticated instruments and technical expertise are grossly underutilized due to limited working hours, few laboratory classes, wear and tear of instruments. This often results in lab instructors clubbing students into groups, providing multiple low end instruments, and limiting lab timings. All these solutions become antithesis to advanced scientific training. To ensure better utilization of resources Remote Triggered (RT) labs, through which real experiments on real instruments can be performed through remote control over internet, have been proposed as the next best option to real labs [Nedic, Z. et al.2003]. Though the touch and feel of real equipment may be missing, yet overall wear and tear of equipment in a RT lab is minimal and hence it is possible to provide access to advanced instrumentation right from early years of education. Thus, RT labs offer untapped potential that may overcome some major limitations faced by real labs and in some cases (e.g. of very complicated or hazardous labs) they may even replace traditional laboratories [M. Auer et.al, 2000;Markan, C. M.et al. 2012].

Now since the development of remote labs grows up, lab developers are facing several problems related to development, accessibility of these labs. Research shows that most remote labs are built by experimentalists with main focus on the pedagogy and very little appreciation of the challenges encountered in adapting their labs for larger audiences with varied hardware and software environments. Further, looking at the growing rate of technology and usefulness of remote labs in education, it has become essential to enhance the scalability of these labs. Unlike simulation based virtual labs, remote labs rely on real instruments controlled by one user at one point of time and hence are in general not scalable unless innovative solutions are researched that introduces 'illusion of parallelism' for multi-user scalability in remote labs.

Therefore, the need of the hour is to undertake a detailed critical review of architectural designs implemented in various existing remote laboratories and come up with a more advanced open-platform for RT Lab Architecture. Such a study is important and timely, as it will lay a framework on which

remote triggered labs can be built thus saving a new entrant in this domain to have safe choice in terms of hardware and software. For example, most existing architectures have not been designed for mobile devices, which seem to be future access devices and thus require revisiting the core platform and reworking from scratch. Apart from use of advanced technologies in architecture design, the real focus of current research will also be to enhance user experience by including interactive GUI of workspace, instrument panels within this architecture with capability of customization for comfort.

2. Literature Review: -

A preliminary literature survey was carried out to understand differences among existing remote laboratories. Several well-known remote labs in the area of electronics and communications were taken into consideration for this survey e.g. iLab, NetLab, VISIR, ISILab, WebLab-Deusto. Some of the features that were reviewed include hardware & software limitation, protocol, programming languages and their importance etc. to evaluate various remote labs. Salient features of these labs are summarized below and as a comparative chart as shown in Table 1.

2.1 iLab (Massachusetts Institute of Technology)

The Massachusetts Institute of Technology's iLab (http://ilab.mit.edu/iLabServiceBroker/) project employs a distributed software toolkit and middleware service infrastructure to support Internet-accessible laboratories and promote their sharing among schools and universities on a worldwide scale. The iLab architecture focuses on fast platform-independent lab development, scalable access for students, and efficient management for lab providers while preserving the autonomy of the faculty actually teaching the students [Harward, V. J et al. 2008].

A first version was developed, called Microelectronics WebLab, based on a Java applet that allowed sending alerts to a server connected directly to the device using Microsoft ASP. [Scapolla, A. Met al. 2005].

2.1.1 Software technologies

The iLab project is not domain specific. It attempts to provide a unifying context and middleware to support online laboratories from a wide variety of fields. Its main features are: a) It allows developing experiments on different platform and operating systems; b) Allows development of both interactive and batch experiments; c) Enables the sharing of experiments between different universities; d) Provide

efficient management tools for laboratory providers; e) It has a scalable design.

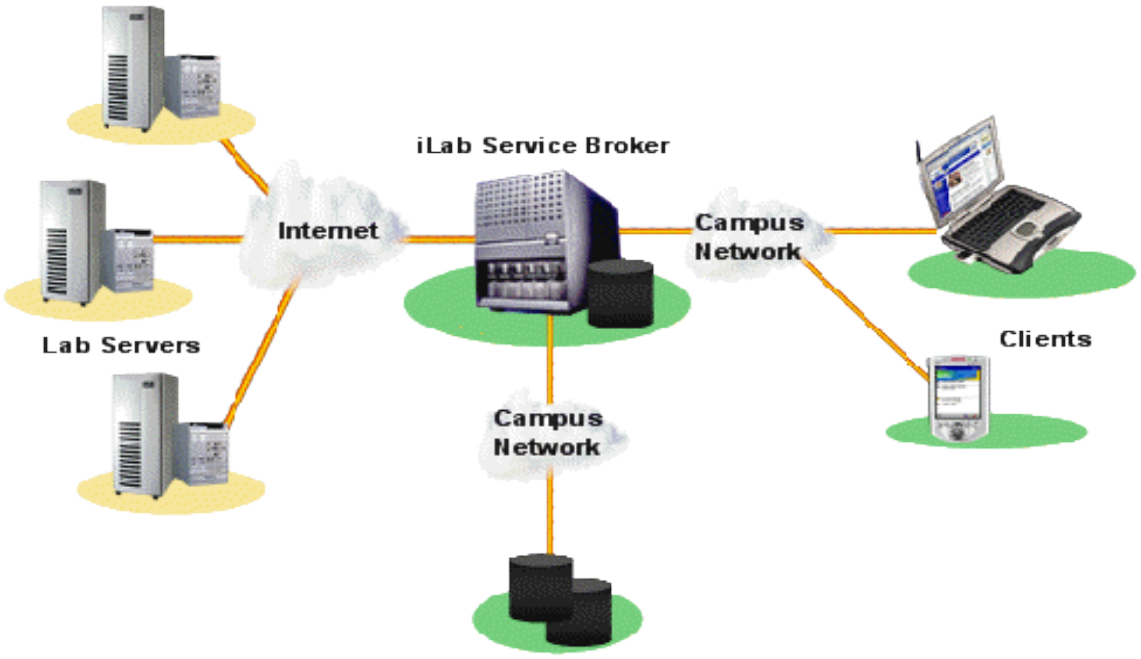


Figure 1 iLab architecture
(**Source:** Auer, M. E., Zutin, D. G. (2011, April)**)**

iLab provides three categorie777s of experiments: 1) Batched experiments, are those in which the entire course of the experiment can be specified before the experiment begins; 2) Interactive experiments are those in which the user monitors and controls one or more aspects of the experiment during its execution. 3) Sensor experiments are those in which users monitor or analyze real-time data streams [Hardison, J. Let al. 2008, October].

2.1.2 Hardware technologies

To control the semiconductor analyzer and the switching matrix used in the iLabs the server contains an Agilent GPIB interface board. Web services make it easier to incorporate vendor supplied modules in the overall architecture. The switching matrix allowed the system to host multiple semiconductor devices for characterization.

Recently, the iLab Project has focused on building remote laboratories around the National Instruments (NI) Educational Laboratory Virtual Instrumentation Suite (ELVIS) platform, an all-in-one electronics workbench. Different iLab based on ELVIS have been developed at MIT, using the data acquisition system available on ELVIS that has software interface running on PC to provide services of hardware

instruments: the Function Generator, the Oscilloscope, DMM, Digital I/O, Bode Anaylzer, etc [Soumare, H., et al. (2009)].

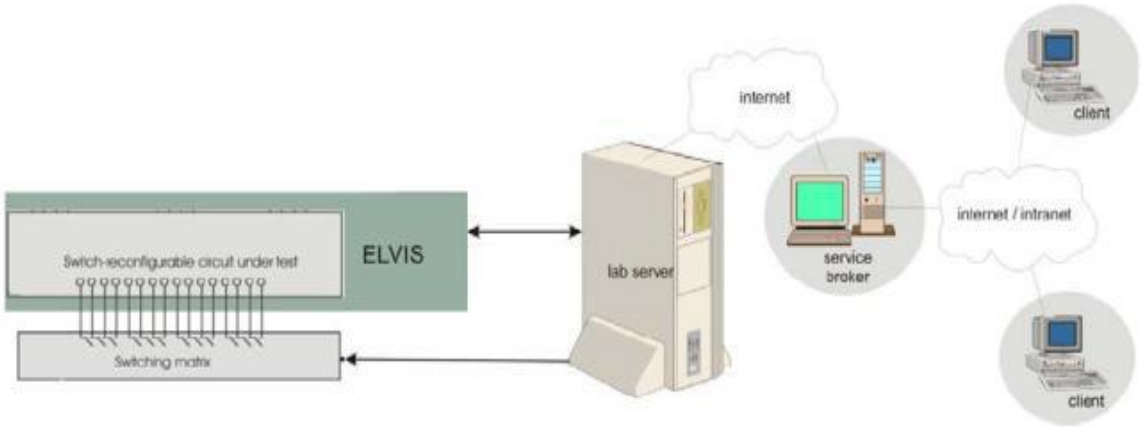


Figure 2 Architecture of iLab based on ELVIS platform
(**Source:** Jiwaji, A., Hardison, J. (2009)**)**

2.2 VISIR Lab (BLEKINGE INSTITUTE OF TECHNOLOGY)

The Signal Processing Department (ASB) at Blekinge Institute of Technology (BTH) has created an online lab workbench known as VISIR (Virtual Instrument Systems in Reality), (https://weblab.deusto.es/weblab/client/#page=home) for electrical experiments, mimicking and supplementing workbenches in local laboratories [Gustavsson, I et al. (2006)]. Using the VISIR interface, the students can create their own electrical circuit and test those using real components and real devices as oscilloscope, function generator, digital multimeter, and a power supply. The user interface has been designed using the same front panels as the students use in the hands-on sessions, so they can reproduce the same actions and procedures as in the real laboratory.

2.2.1 Software technologies

The software architecture used to develop the VISIR lab is shown in Figure 5. This architecture is divided in different servers, each one plays a role in the laboratory set up and experimentation. VISIR is an OpenSource project, so all the software and related information can be download from http://svn.openlabs.bth.se [Gustavsson, I. (2008)]

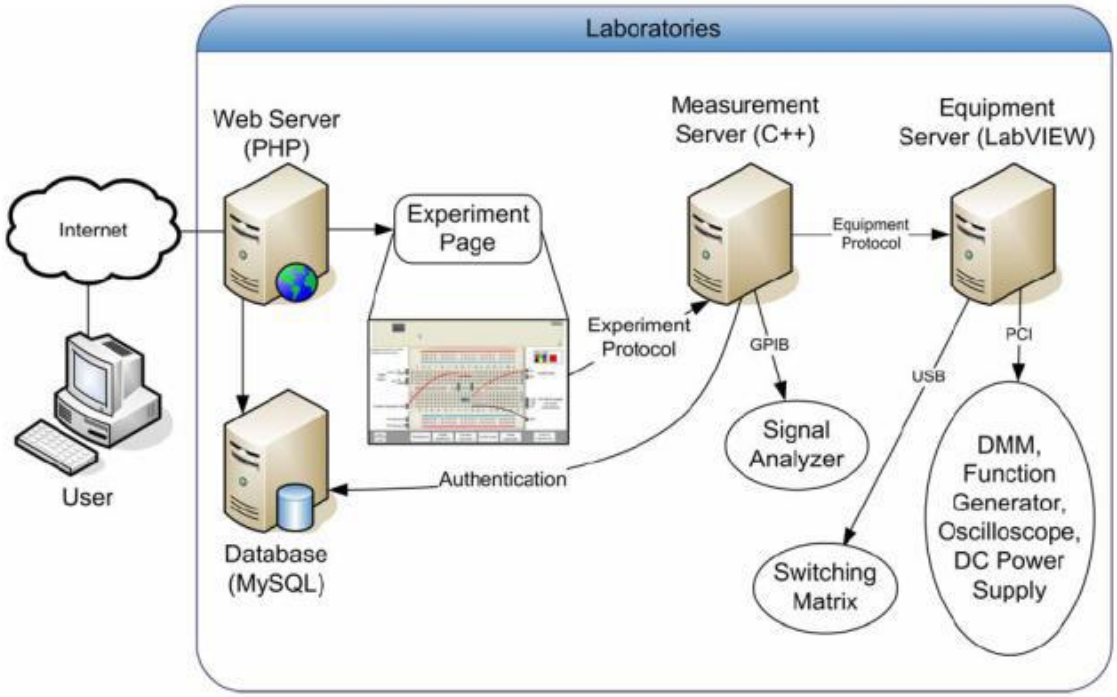


Figure 3 VISIR Lab architecture
(**Source:** Zackrisson, J. (2007, June)**)**

2.2.2 Hardware technologies

VISIR remote lab uses a National Instruments PXI chassis or a PCI solution to gather all the instruments needed to configure and perform measures over the real circuit built by the remote students. The available instruments are: oscilloscope, function generator, digital multimeter and power supply. All these instruments are be from National Instruments, because the LabVIEW Equipment Server is written using the drivers provided by National Instruments. If different manufacturer would be used, the code should be adapted. To build the real circuit designed by the user using the web interface, VISIR uses a proprietary switching matrix also controlled by an Equipment server. The relays are arranged in a three dimensional matrix pattern together with instrument connectors and component sockets. [Gustavsson, I et al. (2008, June)].

2.3 NetLab(Australia)

NetLab (http://netlab.unisa.edu.au/) is an online remote laboratory developed at the University of South Australia. NetLab is currently used by students and staff at the School of Electrical and Information Engineering for practical and demonstration purposes. Being online, NetLab is available to students outside the scheduled practical hours but may also be used by registered visitors. Using a circuit builder,

the user has the chance of creating real experiments through a web site [Nedic, Z. et al. (2007)].

2.3.1 Software technologies

NetLab is a Java based application, so it runs on any operating system provided it has an installation of Java SE runtime environment, version 6.0 or later. To run the NetLab application, students need to download and setup an applet with a shortcut on the desktop [Nedic, N., et al. (2008)]. The actual instrument I/O uses National Instrument's VISA I/O library, through its C programming interface. This is exposed to Java through a created library called JVISA. It exposes most of the VISA API as object-oriented Java interfaces. This requires a very thin wrapper layer written in C which compiles the DLL. The graphical interface is written in Java. All the instrument user interfaces are done using images of the instrument front panels and done graphics using Java's 2D drawing capabilities and the architecture of the NetLab show in (figure 6).

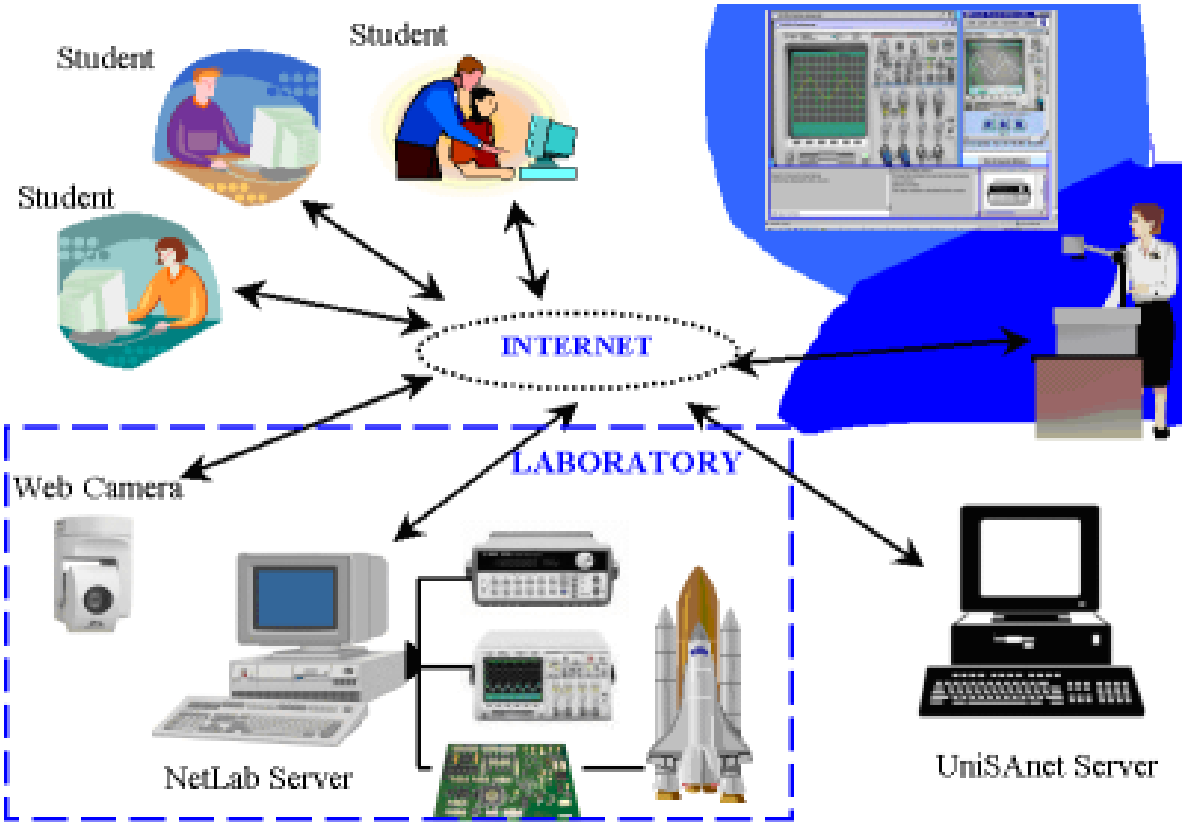


Figure 4 NetLab architecture
(**Source:** Nedic, Z. (2008)**)**

2.3.2. Hardware Technologies

The NetLab's circuit builder is based on a switching matrix with a 16x16 module available from Agilent

(E1465A). This relay matrix switch requires supporting hardware. These components communicate with the NetLab server through the General Purpose Interface Bus (GPIB), while the VXI standard communication protocol is used for the internal communication within the Command Module. The matrix module consists of 256 nodes formed by 16 rows and 16 columns. Nodes are switched thanks to double pole double throw (DPDT) latching relays. The structure of these latching relays allows having two separate layers, which each contain their own set of components [Nedic, Z., et al. (2005)].

2.4 ISILAB (UNIVERSITY OF GENOA)

The Internet shared Instrumentation Laboratory (ISILab) has been developed by the University of Genoa, and currently it is used to deliver remote access or experiments on electronics for the benefit of some engineering courses [Bagnasco, A., et al. (2000)]. The experiments deal with basic electronic measurements, such as the delays in digital circuits or the gain and the distortion of amplifiers and use a waveform generator and an oscilloscope. The laboratory integrates experiements, lectures, exercises, and hand-books that can be accessed through the user interfaces. This remote lab can be accessed at http://isilab.dibe.unige.it/.

2.4.1 Software Technologies

ISILab has been designed using a distributed architecture in which the real laboratories can be spread over a wide geographic area and are accessed seamless by users. The web site portal shows the available experiments, and it is in charge of security policies and establishes the communication between the client and the Real Laboratory Server (RLS) in charge of the selected experiment.

To interact with the experiments, the user doesn’t need any specific hardware or software except for a web browser and the Java Virtual Machine. ISILab has a general purpose and reconfigurable software modules that can be used to control different instruments. These modules can change their appearance and its behavior regarding with a configuration file.This approach is based on the product called AppletVIEW [http://www.nacimiento.com].

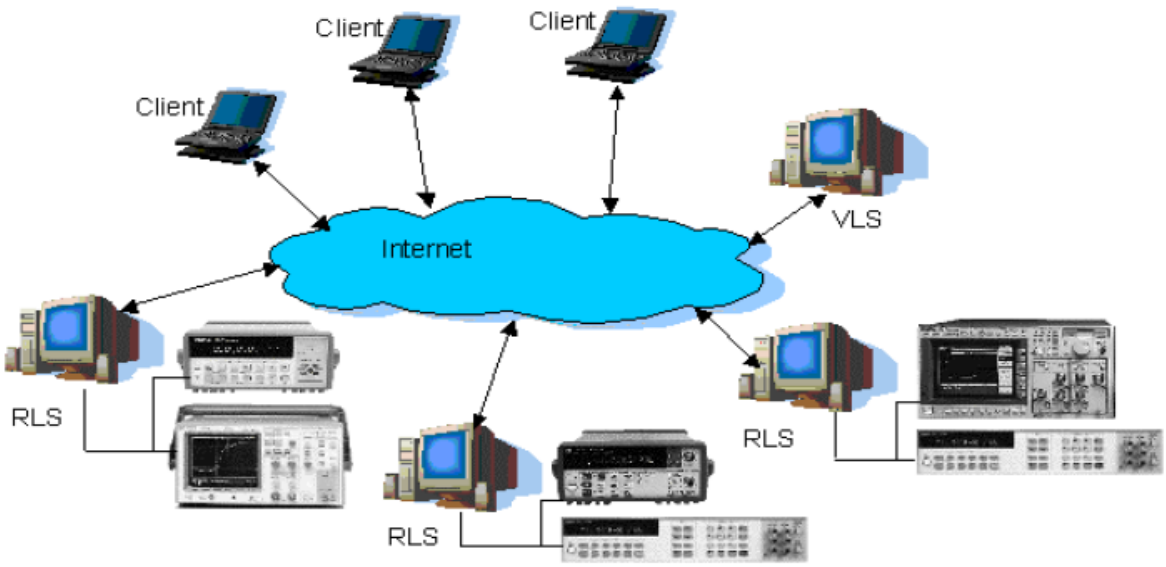


Figure 5 ISILab architecture
(**Source:** Bagnasco, A., Chirico, M., & Scapolla, A. M. (2000).**)**

2.4.2 Hardware Technologies

ISIlab supports both stand-alone instruments and computer-based ones (PCI, PXI, GPIB, etc.). It makes transparent, the hardware using a homogeneous Application Program Interface in the RLS engine. In this way, if a new instrument needs to be added, it only must be wrapped in an appropriate driver adapter to expose the device functionalities. These drivers' adapters are based on IVI (Interchangeable Virtual Instruments) technology [http://www.ivifoundation.org] and they are developed for oscilloscope, function generator and digital multimeter.

If a studentsintends to create a circuit using discrete components, the number of components and relays to interconnect them increases exponentially with the number of components. For this and other reasons [Scapolla, A. M., et al. (2005)], ISI Board has been created. It is a motherboard with sixteen slots, where the experiments cards can be placed. Each card has eighteen lines for providing the power supply, output/input signals and for connections with the instruments. When the circuit is mounted on the motherboard, the connections with the instruments are dynamically created by a set of switches. That is, this motherboard works as a switching matrix controlled by the RLS, because each card has a unique identifier, and a configurable array enables each circuit to share the same instrumentation. Depending on the experiment selected by the user in the web portal, the corresponding card in connected to the instruments and to the portal.

2.5 Weblab Deusto

WebLab-Deusto (http://weblab.deusto.es/website/) is an open source RLMS developed by the University of Deusto since October of 2004. This first version was developed aimed to enable students to program a CPLD through the Internet. Starting from scratch, this first solution was focused on the hardware part of the remote laboratory, attending to the peripherals and the automation of the required tasks: programming a program on a CPLD and interacting with the CPLD inputs.

2.5.1 Software technologies

The first deployment of WebLab-Deusto 2.0 was with a FPGA instead of a CPLD. Since the tools used were the same (Xilinx Impact, serial port), as well as the electronics board, no software change was required. However, it was necessary to have one server for each device (one for the FPGA and the other for the CPLD). However, plans for using WebLab-Deusto with other experiments were built, so the software architecture (figure 8) had to change to enable the administration of multiple remote laboratories. Additionally, maintaining two layers of software with two protocol versions was complicated.

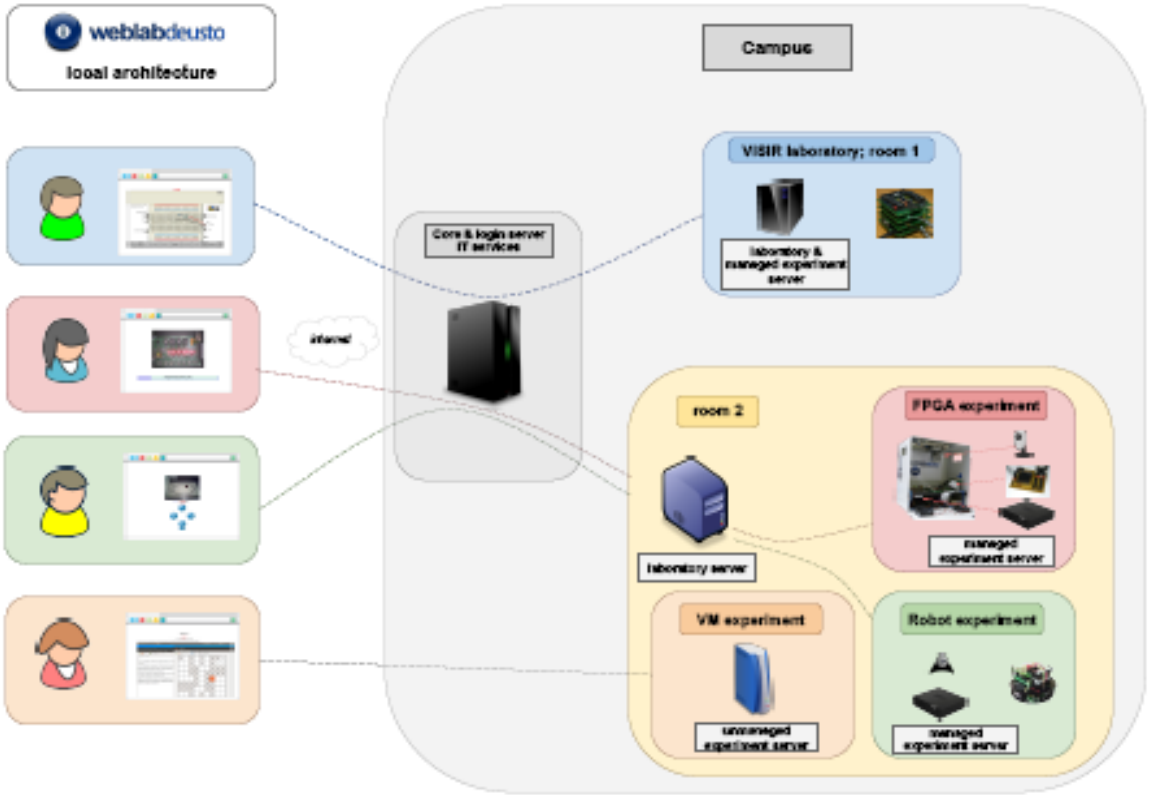
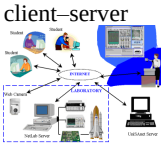
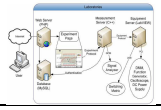


Figure 6 WebLab Deusto architecture
(**Source:** Orduña, P. (2013)**)**

2.5.2 Hardware technologies

WebLab-Deusto uses a layered architecture. Users provide their credentials to an isolated server called login server. This server will validate the credentials and if they are valid, it will contact the core server requesting for a new session. From this point, users will interact with the core server. These credentials can be a username and a password, but also other authentication mechanisms described in the core server perform all the business logic operations. It checks if users are authorized to use a particular laboratory, lists the personal information of the user, will contact other federated environments, will track users, etc. Additionally, most of the interactions with the experiments will go through this server, and it will forward them to the proper server managing the requested or acquired laboratory [Orduña, P. (2013)].

Table 1 Comparison of laboratories architecture based on server and client side technologies

	iLab	**NetLab**	**VISIR**	**ISILab**	**WebLab Deusto**	**Proposed Lab Architecture**
Architecture	shared	client–server 	visir architucture 	distributed	federated	Combination of shared federated and client-server (MVC)
Server-side software	Microsoft IIS, Microsoft SQL Server and Microsoft Visual Studio LabVIEW	C , DLL	HTTP server, PHP 5 or later, Smarty, Text Wiki and MySQL	LabVIEW	Python LabVIEW	Java, Struts2, HTTP server, Reverse proxy, MySQL
Server-side software limitation	Microsoft OS	Linux /Windows/other	Measurement server only use Microsoft OS	Microsoft OS	Linux	Linux /Windows/other
Client-side software	java	java Applet	Flash and PHT5, GWT	java, JVM, XML schema, Applet view	HTML Flash, GWT	Java Applet JavaScript, JQuery, HTML5
Client-side software limitation	Java plug-in requirement	Java plug-in requirement	Only client browser flash required	Java plug-in requirement	Flash plug-in rendering time is to high	Java plug-in requirement All computer
Experiment Type	Fixed	Discrete	Fixed modifiable and discrete	Fixed	Fixed, modifiable	Fixed, modifiable and discrete
Instruments Control Protocols	GPIB, USB, etc.	GPIB-VXI	VXI	PXI, PCI, GPIB under IVI driver	GPIB, USB, LXI, IVI	LAN -*LXI*
Instruments Control Protocols & Limitation	1.0 MB/s-60.0 MB/s	1.0MB/s-80.0 MB/s	80.0 MB/s	1.0 MB/s-80 MB/s	1.0MB/s - 80 MB	125.0 MB/s
Control Software	LabVIEW	JAVA	LabVIEW	LabVIEW	LABVIEW	Java, shell Script

Control Software Limitation	Proprietary Software	Free	Proprietary Software	Proprietary Software	Proprietary Software	Free
Switching Experiment technology	NI-Labview	Switch matrix 16*16	Owner switching matrix	Fixed board according to experiment	Fixed	Switch matrix 16*16
Concurrency on hardware side	no	Single user	Max 16 depending on the experiment	Single user	Single user	Max 16 user can see but single user operate
Concurrency on software side	no	Three users at the same time	Multiple user use and operate	Several users can be watching the experiment at the same time but operate single user	Multiple user use according to queue manageme nt	Multiple user use and operate

3. Motivation

Govt. of India under its ambitious objective of Right to Education initiated a National Mission on Education through Information & Communication Technology (NME-ICT) with an aim to use the immense accessibility of Information and communication technology to shatter the mythical divide of educational resources available in the country and beyond. This inclusive growth story visualizes reaching out to the most untouched and underprivileged citizens of India irrespective whether they are from urban, rural or tribal regions.

In this regard the Ministry of Human Resources floated a pilot project on Virtual Labs with an objective to explore methodologies to provide laboratory education to a remote student who has no access to any form of laboratory facility. Ten institutes that include all eight IITs (Indian Institute of Technology), Dayalbagh University and one other Indian university (see figure 9) were chosen amongst those who volunteered to take up this challenging assignment with little or no precedent available to them.

Several Remote Triggered Labs were developed under this flagship program. In the absence of any comprehensive understanding many different methodologies were incorporated, most of them were successful in building upto a prototype. However, when required to scale to larger audience many of these labs faced severe difficulties in providing services due to choices of hardware/software architecture, methodology and at times use of proprietary software. Hardly any of these labs had the capacity to be effectively used on mobile devices. Therefore, the need of the hour is to review the existing methodologies towards design and development of remote labs and come up with comprehensive best practices that not only help in understanding limitations of current methods but also

will serve as an ideal starting point. Such a study will encourage many newcomers to attempt with the correct understanding and will therefore ensure the impetus towards building remote triggered labs so that not lost in the maze of technological challenges.

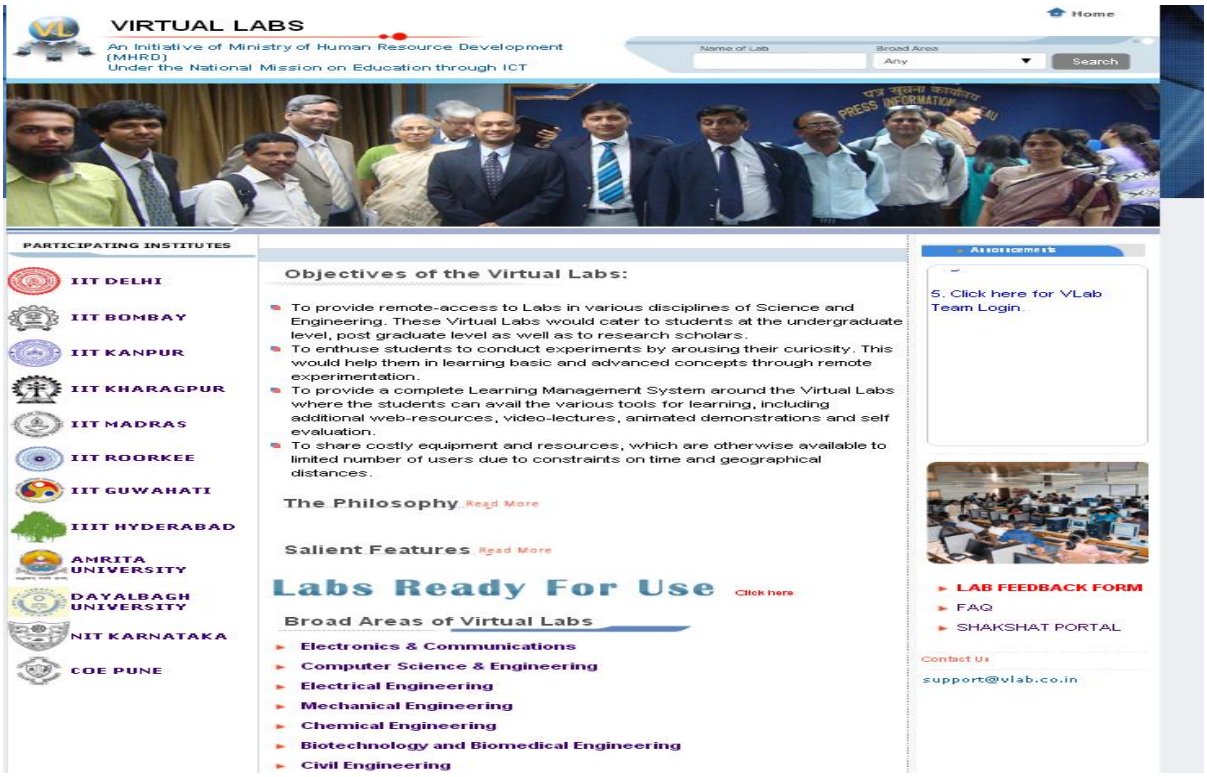

VIRTUAL LABS
An Initiative of Ministry of Human Resource Development (MHRD)
Under the National Mission on Education through ICT
Home
Search
PARTICIPATING INSTITUTES
IIT DELHI
IIT BOMBAY
IIT KANPUR
IIT KHARAGPUR
IIT MADRAS
IIT ROORKEE
IIT GUWAHATI
IIIT HYDERABAD
AMRITA UNIVERSITY
DAYALBAGH UNIVERSITY
NIT KARNATAKA
COE PUNE
Objectives of the Virtual Labs:
To provide remote-access to Labs in various disciplines of Science and Engineering. These Virtual Labs would cater to students at the undergraduate level, post graduate level as well as to research scholars.
To enthuse students to conduct experiments by arousing their curiosity. This would help them in learning basic and advanced concepts through remote experimentation.
To provide a complete Learning Management System around the Virtual Labs where the students can avail the various tools for learning, including additional web-resources, video-lectures, animated demonstrations and self evaluation.
To share costly equipment and resources, which are otherwise available to limited number of users due to constraints on time and geographical distances.
The Philosophy Read More
Salient Features Read More
Labs Ready For Use Click here
Broad Areas of Virtual Labs
Electronics & Communications
Computer Science & Engineering
Electrical Engineering
Mechanical Engineering
Chemical Engineering
Biotechnology and Biomedical Engineering
Civil Engineering
Assignments
5. Click here for VLab Team Login.
LAB FEEDBACK FORM
FAQ
SHAKSHAT PORTAL
Contact Us
support@vlab.co.in

Figure 7 Snapshot of Virtual Labs website showing list of participating institutions and some of the labs developed by these institutions under the NMEICT Virtual Labs Program (**Source:** https://www.vlab.co.in/participating-institutes).

Therefore, there is a need to evolve a **standardized Open Platform**, that will consist basic and advanced modules to develop a remote laboratory e.g. web server, instrument server, user management system etc. it will also eliminate a lot of effort from remote lab developers without getting into complex task of programming modules for remote labs and integration of these modules. Another advantage of a standard platform would be common user interfaces design pattern followed among the laboratories. This will benefit the students without putting up the extra burden of training to use different remote laboratories.

Besides this, this Standardized Open platform will also enable sharing of laboratory resources, spatially localized at different places. This kind of structure will make use of unutilized laboratory resources due to flaws in software mechanisms. In broad terms, the current model will also enable us to provide On-Demand RT lab services to the clients, which is similar to SaaS (Software as a service) & IaaS

(Infrastructure as a service) model of Cloud computing. So, this will give rise to a new era of cloud computing in remote labs domain.

4. Objectives:

Broadly our research efforts will review the existing remote labs to critically examine the existing methodology used and to come up with a Generic Remote Laboratories Architecture, which will cover the following research objectives.

1. To study and explore the fundamental components necessary for constructing an on-demand cloud-based remote laboratory architecture, focusing on the integration and teleoperation of real laboratories.
2. To explore and develop a methodology for setting up independent applications within a cloud-based remote laboratory, ensuring this application can interact seamlessly with each other.
3. To create and evaluate a scalable scheduling system that supports slot booking and queue management, enhancing the scalability of the cloud-based remote laboratory architecture.
4. To design an integrated GUI that supports basic and advanced learning, enhances e-learning with on-demand services, and seamlessly integrates hardware circuits and simulation outputs from different manufacturers.
5. To explore and design a Generic Remote Laboratories Architecture capable of supporting various types of remote labs on a unified platform, intelligent tools, ensuring broad applicability and ease of use.

Methodology: We will undertake this study in following steps

- We will undertake critical review of Remote Labs both well established internationally and those developed under the NMEICT
- Based on this review we will propose an Open Platform Architecture suited across various hardware and software platforms.
- We will design a platform with tools and facilities for building a remote lab from scratch.
- We will build at least one remote triggered lab based on this architecture demonstrating various features with capability of scalability.
- We will integrate the remote triggered lab with LMS to provide a comprehensive learning

experience.

Conclusions:

We believe that efforts to critically review existing architectures and building an open platform for remote lab architecture is need of the hour as this effort needs more encouragement to bring in some more talent and involvement. It is felt that paradigm shift from local laboratories to remote labs can propel our country's vision to provide quality education at the doorstep of the learner into a reality. Further, scalable remote labs make kick start services from equipment manufacturers to provide laboratory as a service enriching the learning environment and remove the existing helplessness of seeing faulty, substandard and non-functional laboratory facilities.

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